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Abstract of

A Thesis

Presented in Partial Fulfillment of the Requirements for  
the Degree Master of Science

By

ALBERT STEVENSON SMITH, B.S.

The Ohio State University

1958

Approved by:

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Advisor

March  
1933

March 3

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# A NEW METHOD OF MEASURING SHORT HALF-LIVES

DELBERT SILVSTER BARTH

U.S., United States Military Academy, 1946

Department of Physics  
(Approved by James C. Harris)

A review of several methods of measuring the half-lives of short-lived radioisotopes is presented. Then a new method is described which utilizes a cathode ray oscilloscope in conjunction with three phototubes and associated electrical circuits. The design and construction of the concomitant apparatus is taken up in detail. The method described is then applied to the specific problems of measuring the half-lives of the isotopes aluminum twenty-five and aluminum twenty-six, which result from the bombardment of magnesium twenty-four and magnesium twenty-five respectively with protons accelerated by a Van de Graaff generator. The values obtained for the half-lives are reported as follows: aluminum twenty-five -- seven and eleven hundredths seconds plus or minus thirteen hundredths of a second; aluminum twenty-six -- seven and sixty-one hundredths seconds plus or minus twenty-one hundredths of a second. In conclusion the capabilities and limitations of the new method described are delineated, and future applications are suggested.





A NEW METHOD OF MEASURING SHORT HALF-LIVES

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Adviser



THE UNIVERSITY OF CHICAGO

PHYSICS DEPARTMENT

REPORT OF THE COMMITTEE ON THE

PROGRESS OF THE DEPARTMENT

FOR THE YEAR 1900-1901

PRESENTED TO THE FACULTY

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The author wishes to take this opportunity to express his sincere appreciation to Professor James C. Harris and Professor John H. Cooper for their constant assistance and guidance throughout this work. Thanks are also due to Donald A. Green for his assistance in taking the data.

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## Historical Review and Introduction

Before proceeding to a description of a new method of measuring the half-lives of short-lived radioisotopes it is perhaps advisable to describe some of the methods which have been used successfully in the past. In this regard A. W. K. (1) has given an excellent review of several methods, some of which will now be discussed.

Attempts to measure the half-life of  $\text{Ra C}'$  ( $1.55 \times 10^{-4}$  sec.) gave rise to three different methods of measuring short half-lives, all of which depend on the radioactive daughter isotope of interest being formed from a radioactive parent whose half-life is long compared to that of the daughter. These methods may be called (1) the pulse-lengthening method, (2) the delayed pulse method, and (3) the oscilloscope method.

The pulse-lengthening method has been developed by Danforth (2) and Rotblat. (3), (4) It utilizes two counters, one of which is sensitive to the beta radiation from  $\text{Ra C}$  and one of which is sensitive to the alpha radiation from  $\text{Ra C}'$ . The pulses from the two counters are amplified separately, made of uniform size, and then fed into a coincidence circuit. The length of the beta pulses is varied and the number of coincidences per unit time observed as a function of the length of the pulse. That the graph of the coincidences per unit time versus the length of the pulse is the inverse of



Before proceeding to a description of a new system of  
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the  $\text{Ra C}'$  decay curve may be seen from the considerations below.

The general law of radioactive decay may be written as

$$N = N_0 e^{-\lambda t} \quad (1)$$

where  $N$  = the number of atoms of a radioactive material remaining at the end of a time  $t$ ;  $N_0$  = the initial number of atoms; and  $\lambda$  = the decay constant.

If  $N_0$  be put equal to one and the differential of (1) taken, the result is

$$dN = -\lambda e^{-\lambda t} dt \quad (2)$$

From (2) it may be seen that the probability for a given atom to live a time  $t$  and then decay in the interval from  $t$  to  $t+dt$  is  $\lambda e^{-\lambda t} dt$ . Thus the probability for the emission of an alpha particle during the time  $\tau$ , or what is the same thing, the rate of coincidence when the beta pulse has a length  $\tau$  is

$$C = N_0 \int_0^\tau \lambda e^{-\lambda t} dt \quad (3)$$

where  $\lambda$  is the decay constant of  $\text{Ra C}'$  and  $N_0$  is the initial number of  $\text{Ra C}'$  atoms.

Evaluating the integral in (3) leads to

$$C = C_{\max} (1 - e^{-\lambda \tau}) \quad (4)$$

where  $C_{\max}$  is the maximum coincidence rate, which will be attained when  $\tau$  becomes infinite. For infinite  $\tau$ ,  $C = C_{\max} = N_0$ . From (4) it can be seen that the coincidence rate increases exponentially with the beta-pulse length in a manner

and as  $\lambda$  varies over the real line the eigenvalues

of the matrix  $A(\lambda)$  are given by

$$(1) \quad \lambda = \lambda_1, \lambda_2, \dots, \lambda_n$$

where  $\lambda_1, \lambda_2, \dots, \lambda_n$  are the eigenvalues of  $A(0)$ . If  $\lambda_1, \lambda_2, \dots, \lambda_n$  are all real, then the eigenvalues of  $A(\lambda)$  are real for all  $\lambda$ . If  $\lambda_1, \lambda_2, \dots, \lambda_n$  are not all real, then the eigenvalues of  $A(\lambda)$  are not all real for all  $\lambda$ .

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$$(5) \quad \lambda = \lambda_1, \lambda_2, \dots, \lambda_n$$

where  $\lambda_1, \lambda_2, \dots, \lambda_n$  are the eigenvalues of  $A(0)$ . If  $\lambda_1, \lambda_2, \dots, \lambda_n$  are all real, then the eigenvalues of  $A(\lambda)$  are real for all  $\lambda$ . If  $\lambda_1, \lambda_2, \dots, \lambda_n$  are not all real, then the eigenvalues of  $A(\lambda)$  are not all real for all  $\lambda$ .



determined by the decay constant  $\lambda$ . Hence it is possible to compute the half-life of Ra C' from the experimental relationship observed between the coincidence rate and the length of the beta pulse.

The delayed pulse method has been developed by Jacobson and Sigurgeirsson (5). As in the previous method two counters are used, one sensitive only to beta radiation and the other sensitive only to alpha radiation. The outputs of the two counters are fed into a coincidence circuit as before. Now, however, instead of lengthening the beta pulse the arrival of the beta pulse is delayed a variable length of time. As before the probability that an atom decays in the interval between  $t$  and  $t+dt$  is  $\lambda e^{-\lambda t} dt$ . When the pulse widths are short compared to the half-life being measured this is equivalent to the probability that a coincidence be recorded after the beta pulse has been delayed  $t$  units of time. Therefore the coincidence rate may now be expressed as

$$C = N_0 \int_{\tau}^{\tau+\tau_c} \lambda e^{-\lambda t} dt \quad (5)$$

where  $\tau$  is the delay time of the beta pulse;  $\tau_c$  is the maximum length of time by which two pulses may be separated and still be recorded as a coincidence;  $\lambda$  is the decay constant of Ra C' ; and  $N_0$  is the initial number of Ra C' atoms. Integration of (5) gives

$$C = N_0 e^{-\lambda \tau} (1 - e^{-\lambda \tau_c}) \quad (6)$$

If one now denotes by  $C_0$  the value of  $C$  when  $\tau = 0$ , it is

1. The first group of people who are likely to be affected by the proposed changes are those who are currently employed by the company. It is estimated that approximately 100 employees will be affected by the proposed changes. The company is currently employing 100 employees, and it is estimated that approximately 100 employees will be affected by the proposed changes.

1944

It is not possible to determine the exact date of the birth of the child, but it is believed that the child was born in the year 1880.

36-36

easily seen that

$$N_0 = C_0 / (1 - e^{-\lambda \tau_0}) \quad (7)$$

With this substitution (6) becomes

$$C = C_0 e^{-\lambda \tau} \quad (8)$$

From (8) it is clear that a graph of the observed rate of coincidence versus the delay time of the beta pulses will give a decay curve for  $\text{Ra C}'$  from which the half-life may be easily computed.

The oscilloscope method has been developed by Howlands. (6), (7) Two counters are used as in the previous two methods. This method does not, however, utilize a coincidence circuit. Instead, the beta pulse is used to trigger a single sweep on a cathode ray oscillograph and the alpha pulse is applied to the vertical deflection plates. By this means it is possible to observe directly the time intervals between pulses simply by noting the position of the alpha pulse on the oscillograph screen. The number of alpha pulses observed after a time delay  $\tau$  will be

$$N = N_0 \int_{\tau}^{\tau + 4\tau} \lambda e^{-\lambda t} dt \quad (9)$$

where  $4\tau$  is the smallest unit of time observable on the oscillograph time scale being used;  $\lambda$  is the decay constant of  $\text{Ra C}'$  and  $N_0$  is the initial number of  $\text{Ra C}'$  atoms. As in the delayed pulse method this may be readily integrated to give

$$N = N_0' e^{-\lambda \tau} \quad (10)$$

where now  $N_0'$  is the number of alpha pulses having a zero time



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$$(17) \quad \dots \dots \dots$$

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$$(18) \quad \dots \dots \dots$$

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$$(19) \quad \dots \dots \dots$$

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$$(20) \quad \dots \dots \dots$$

... ..

delay; by analogy to (7)  $N_0'$  is equal to  $N_0 (1 - e^{-\lambda \Delta \tau})$ .

So it is evident that a plot of alpha pulses versus observed delay times will give a decay curve for  $N_0'$  from which the half-life can be easily determined.

It appears on the surface as though none of the three methods just described could be utilized to measure the half-life of a radioactive isotope which is the sole product nuclei of, say, a nuclear reaction and which decays to a stable isotope. Actually, however, De Benedetti and McGowan<sup>(26)</sup> have shown that the delayed pulse method may be used to measure the half-life of a single isolated radioactive material. Several other methods also applicable to this case will now be discussed.

In a method originated by Mosely and Fajans<sup>(8)</sup> and developed by Becker and Gaertner<sup>(9)</sup> a target is deposited on a disk which rotates at high speed. The target is then bombarded with nuclear projectiles from some sort of an accelerator, and the activity is measured as a function of the angular displacement from the point of bombardment. From this data the half-life of the activity may easily be computed.

Cassels and Nathan<sup>(10)</sup> have used a cyclotron modulated to give short bursts of particles. In between the bursts, the counter measuring the radioactivity of the target is connected in turn for equal time intervals to each of ten





separate recorders. The half-life of the activity may then be easily computed from the data obtained. Jassols and Iothan claim that this method is good for half-lives ranging from 100 microsec. to 1 sec. The factor which sets a lower limit to the half-life measurable by this technique is the recovery time of the counter being used to measure the activity. The use of scintillation counters, which have recovery times on the order of  $10^{-3}$  sec., would increase the range of applicability of this method considerably.

For half-lives longer than a few seconds, a target may be bombarded and then removed to an adjacent counter of some sort which measures the activity and the decay of the induced radioactivity. The main difficulties in this procedure are getting the radioactive target from the place of bombardment to the counter before the activity has decayed too much, and devising a timing mechanism to accurately fix the time intervals during which the counter counts. The number of counts obtained must also be recorded in some fashion. The counting interval should, of course, be reasonably small compared to the half-life being measured. Different research workers<sup>(1), (11), (12)</sup> have devised various methods to surmount the difficulties mentioned. For more specific information the literature may be consulted.

In general the methods for measuring short half-lives just described have limited ranges of applicability and require complicated electronic circuits which are not avail-

[illegible]

able commercially. The new method which will be described in this thesis has a range of applicability from approximately 1 millisecc. to 1 min. and utilizes for the most part commercially available equipment. The associated electrical circuits which must be constructed are simple in design and not difficult to assemble. Although the method was designed for use with a Van de Graaff generator, it could easily be adapted for use with any other type of accelerator. After the general theory and construction of the equipment have been discussed, descriptions of two experiments utilizing the method will be given. The results of these experiments will be discussed and finally future applications of the method will be suggested.

### General Description of Method and Equipment

The method discussed below was devised for use with the Van de Graaff generator at Ohio State University. A general description of the pieces of equipment necessary and the tasks performed by each follows.

A shutter was constructed to interrupt the Van de Graaff generator beam. Simultaneously with interrupting the beam the shutter actuates a microswitch which in turn actuates a relay raising a lead shield from between the target being bombarded and an active Geiger tube. The pulses from the



The total amount shown was divided for the gift of \$100 to each of the two children, a total of \$200.

1. The first step in the process of identifying a problem is to determine the nature of the problem. This involves a thorough understanding of the situation and the factors that are contributing to the problem. Once the nature of the problem is understood, the next step is to identify the causes of the problem. This involves a detailed analysis of the situation and the factors that are contributing to the problem. Once the causes of the problem are identified, the next step is to develop a plan of action to address the problem. This involves determining the steps that need to be taken to address the problem and the resources that will be required to implement the plan. Once a plan of action has been developed, the next step is to implement the plan. This involves carrying out the steps that have been identified in the plan of action. Finally, the last step in the process is to evaluate the results of the plan. This involves determining whether the plan has been successful in addressing the problem and whether any further action is needed.

Geiger tube are fed into the vertical deflection plates of a cathode ray oscilloscope. The microswitch mentioned before also closes an electric circuit which triggers a single sweep of the electron beam across the face of the oscilloscope. Positioned at definite intervals along the time axis of the oscilloscope are three lucite tubes which pipe light to three separate type 931-A photomultiplier tubes. Each photomultiplier tube is followed by its own preamplifier and its own independent scaler. Thus during a single sweep of the electron beam across the face of the oscilloscope a certain number of pulses will be "seen" by each phototube and recorded on the appropriate scaler. This will give three points on a decay curve of the activity being counted. Of course, this routine must be gone through many times to obtain sufficient counts on each scaler to give a small probable error. The time base of the oscilloscope sweep must be adjusted to a value commensurate with the half-life of the activity being measured.

It is seen from the preceding description of the new method that the equipment necessary is:

- (1) A Van de Graaff generator.
- (2) A shutter for interrupting the Van de Graaff generator beam.
- (3) A Geiger tube.
- (4) A cathode ray oscilloscope.
- (5) Three phototubes with individual preampli-

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2. The second is the fact that the Commission has not yet received any information from the Government of the United Kingdom regarding the progress of its investigation into the matter.

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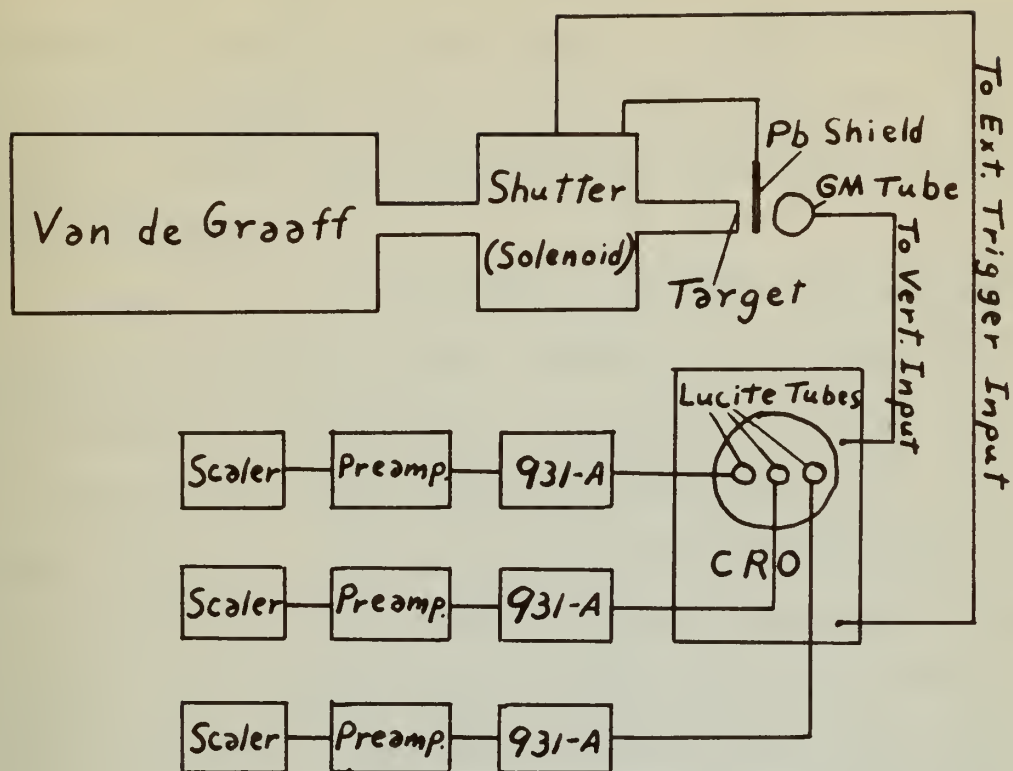


Figure 1. Sketch of arrangement of various equipment.





fiers and independent outputs.

(6) Three scalars.

(7) Various voltage supplies.

Figure 1 is a sketch illustrating the proper relationship of this equipment. Items (2) and (5) in the above list require a special description since they had to be designed and constructed.

Figure 2 is a sketch of the shutter used in this work. As can be inferred from the sketch the motivating force for the shutter is provided by a solenoid. When this solenoid is actuated by a hand switch in series with a 200 volt D. C. power supply the soft iron core is drawn inside the solenoid, cutting off the Van de Graaff beam and actuating the micro-switch. The solenoid draws 70 milliamperes of current. When the hand switch is turned off a spring draws the shutter back so that the Van de Graaff beam is again bombarding the target.

Figure 3 is a circuit diagram of one phototube and its preamplifier. There are two more identical units. Several general references were consulted in the design of these circuits. (13), (14), (15), (16), (17)

Figure 4 is a photograph of all three units complete, showing the lucite tubes and the framework by which the whole is fastened to the face of the oscilloscope. The lucite tubes were first shaped and then cemented to the 931-A phototubes by means of Canada balsam. The phototubes were



(6) *Formal analysis*

(7) *Subjective analysis*

Figure 1 is a general illustration of the process of analysis.

At this point, Figure 1 and 2 are the same. Figure 1 is a general illustration of the process of analysis. Figure 2 is a general illustration of the process of analysis.

Figure 3 is a general illustration of the process of analysis.

Figure 4 is a general illustration of the process of analysis.

Figure 5 is a general illustration of the process of analysis.

Figure 6 is a general illustration of the process of analysis.

Figure 7 is a general illustration of the process of analysis.

Figure 8 is a general illustration of the process of analysis.

Figure 9 is a general illustration of the process of analysis.

Figure 10 is a general illustration of the process of analysis.

Figure 11 is a general illustration of the process of analysis.

Figure 12 is a general illustration of the process of analysis.

Figure 13 is a general illustration of the process of analysis.

Figure 14 is a general illustration of the process of analysis.

Figure 15 is a general illustration of the process of analysis.

Figure 16 is a general illustration of the process of analysis.

Figure 17 is a general illustration of the process of analysis.

Figure 18 is a general illustration of the process of analysis.

Figure 19 is a general illustration of the process of analysis.

Figure 20 is a general illustration of the process of analysis.

Figure 21 is a general illustration of the process of analysis.

Figure 22 is a general illustration of the process of analysis.

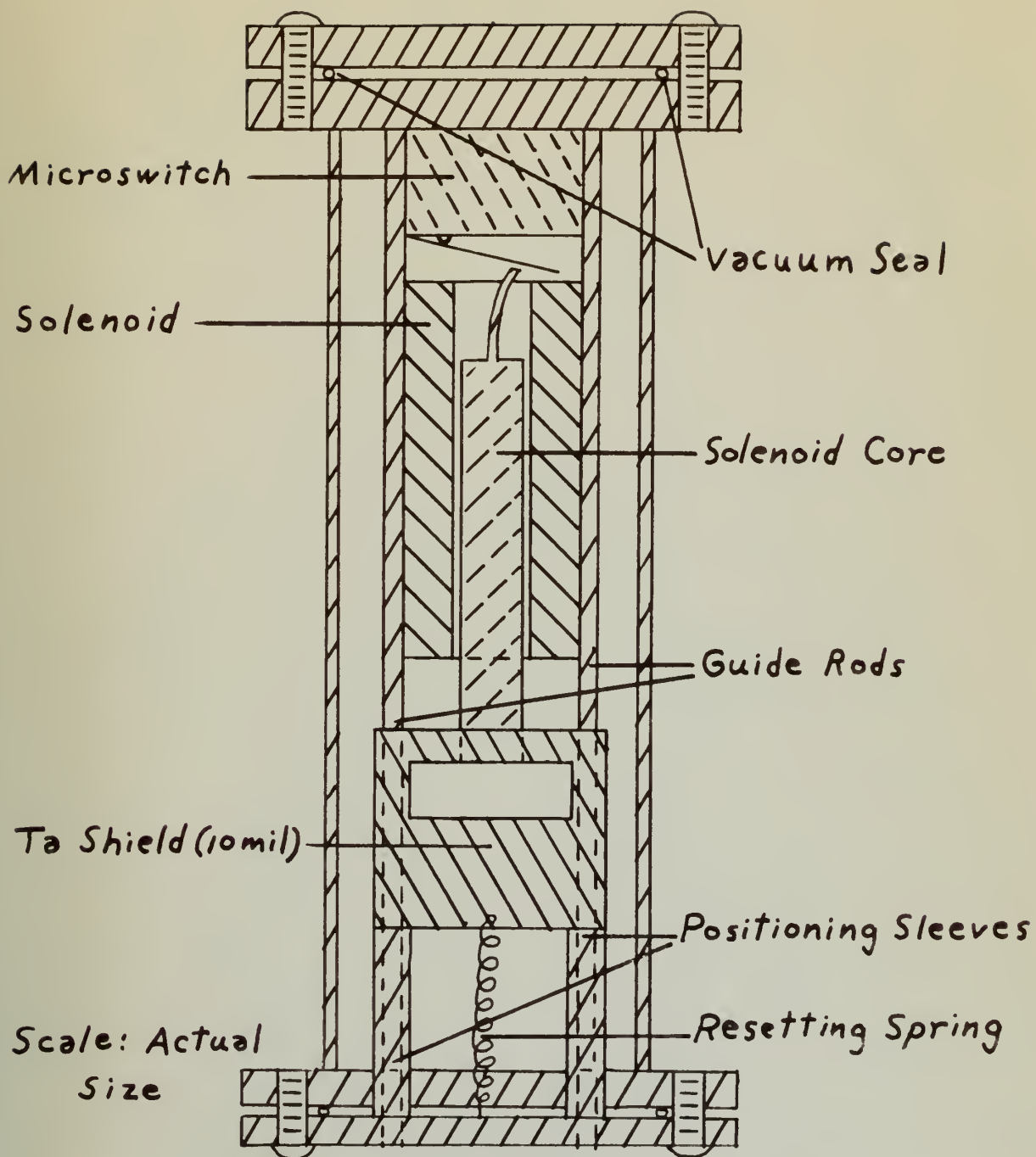


Figure 2. Cross-sectional sketch of shutter.



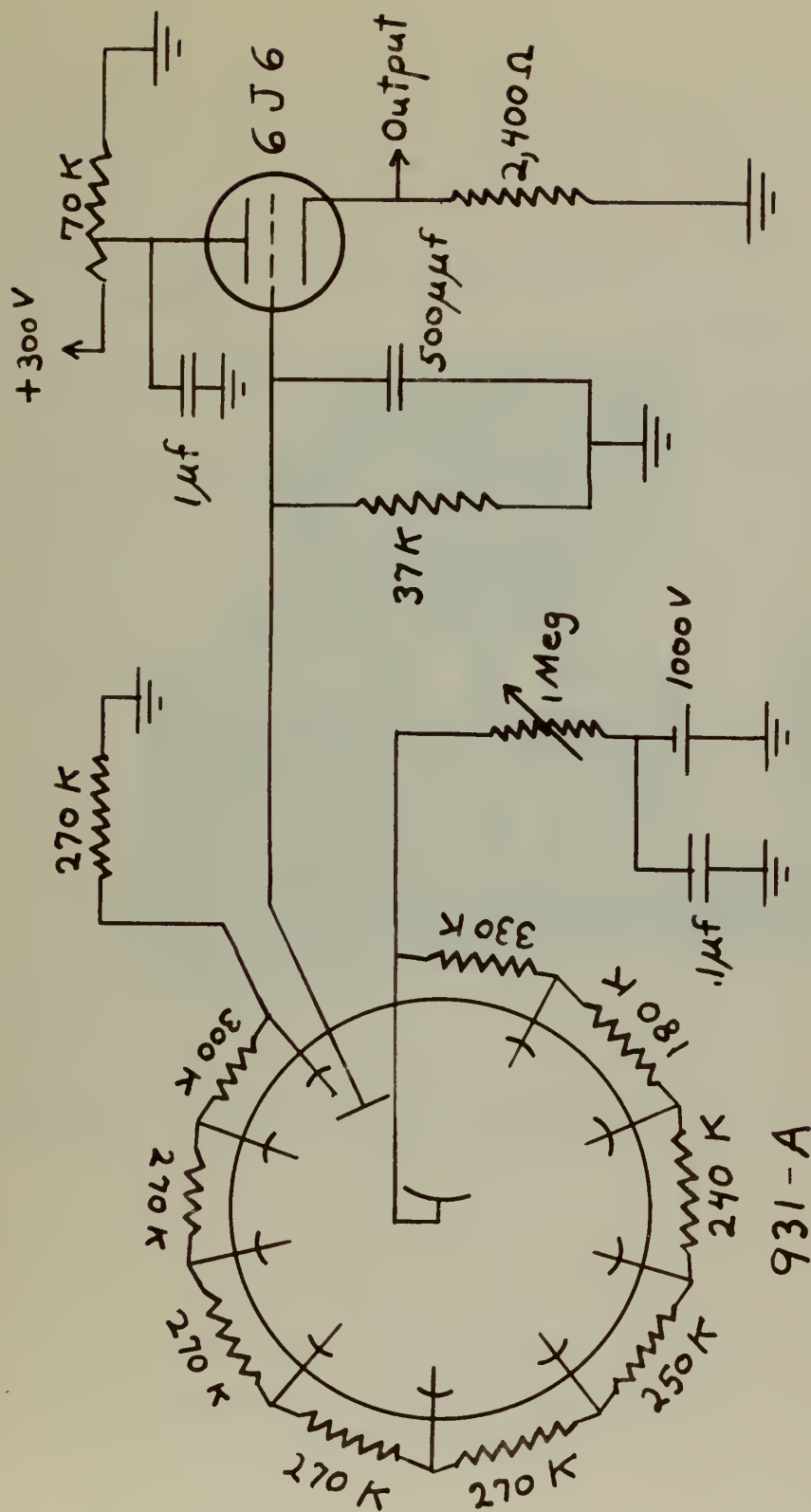


Figure 3. A typical phototube-preamplifier unit.



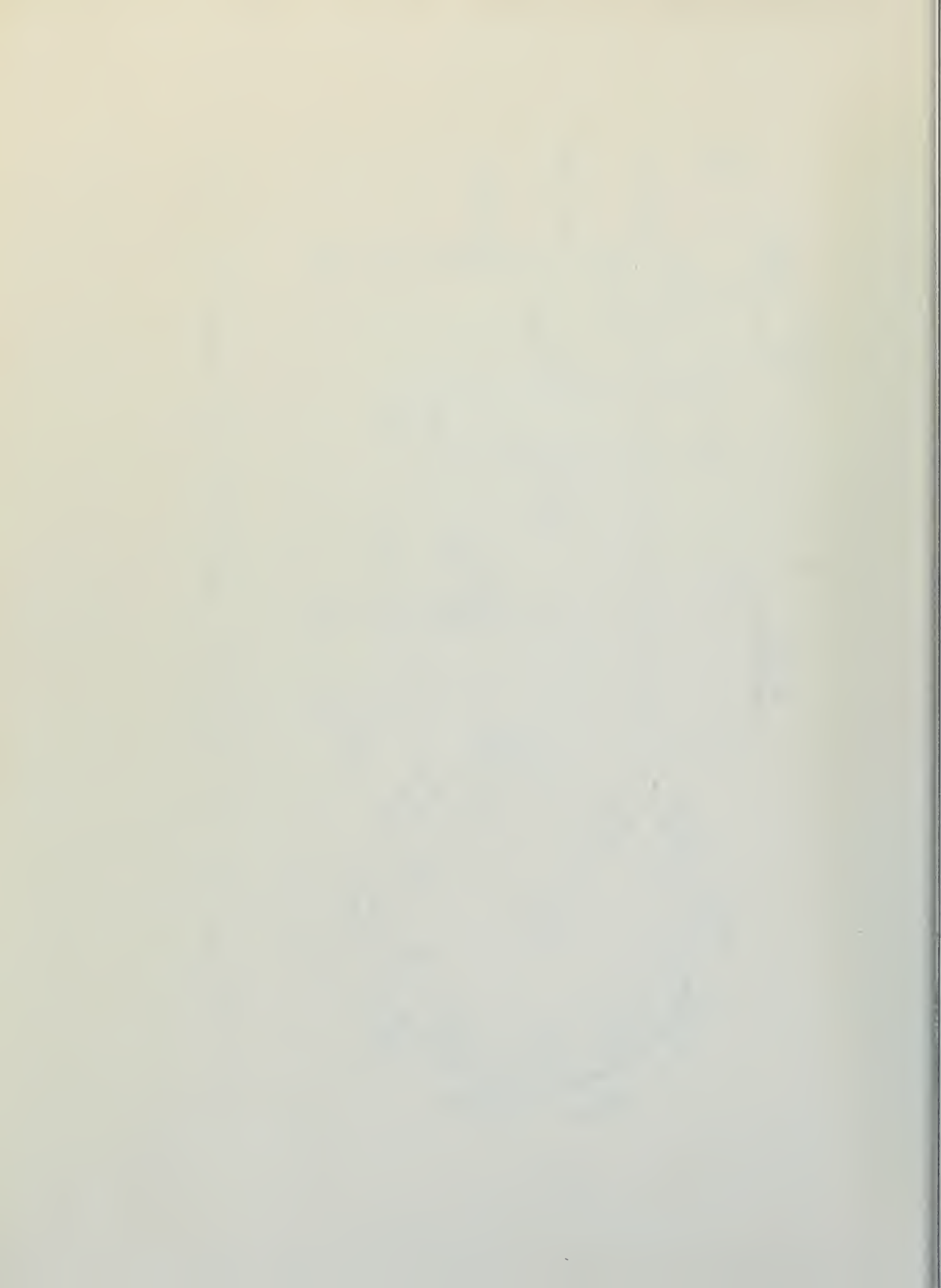
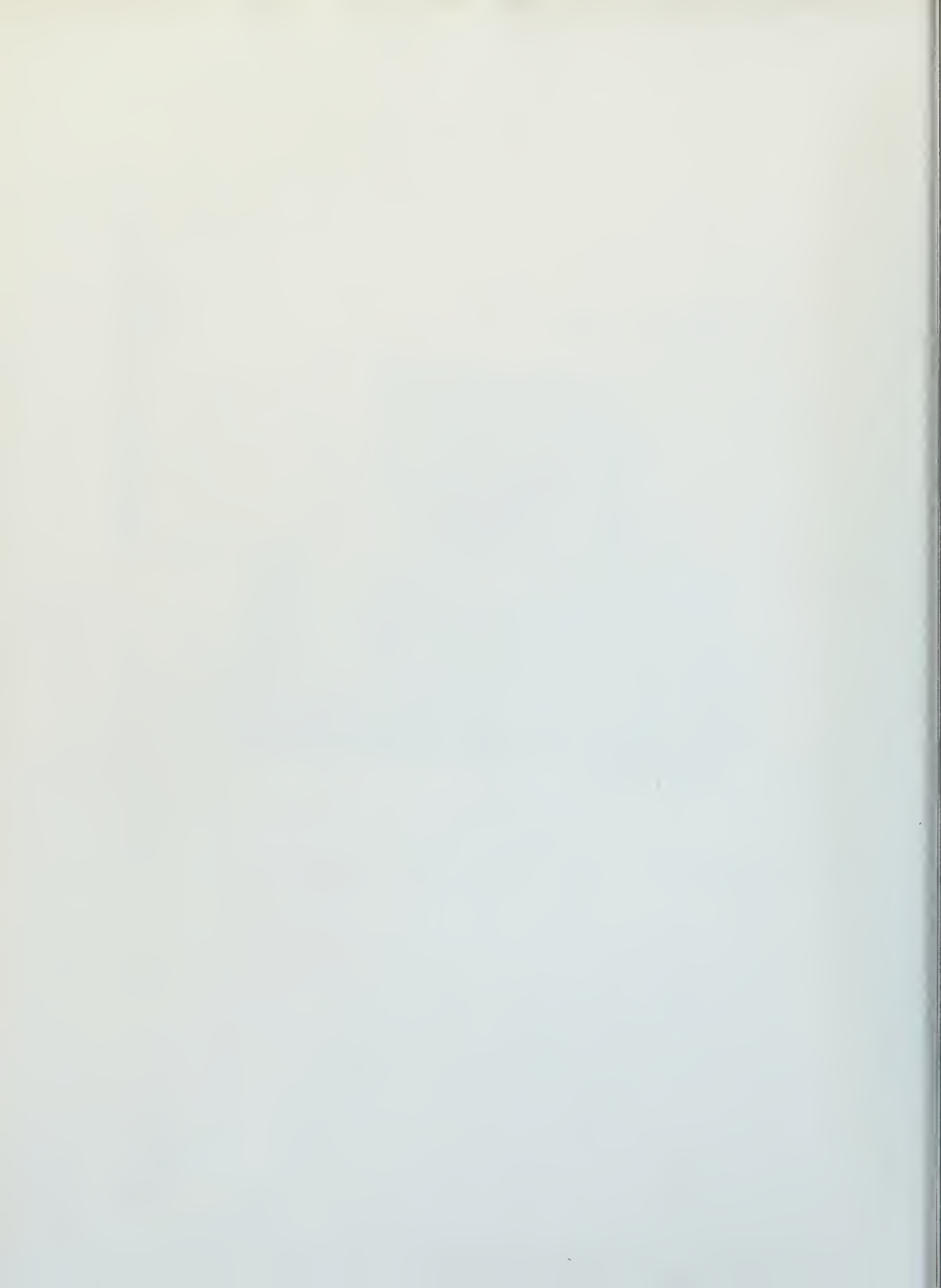




Figure 4. Photograph of complete phototube - preamplifier unit.



painted black to keep out undesired stray light. A pressure fit for the end of the lucite tubes against the face of the oscilloscope was found to be satisfactory. It should be noted that the variable resistances placed in the phototube circuits permit independent adjustment of the voltage across each phototube (within certain limits). This was found to be necessary since the 931- tubes used did not have precisely the same characteristics as a function of voltage. It is imperative that the same number of counts be registered by each phototube from the same source of light impulses. By adjusting the voltage properly on each phototube it was possible to attain this desired condition.

#### Specific Experiments Performed

After this equipment was designed and constructed, it was decided to apply it to the problem of determining the half-lives of the two radioisotopes  $Al^{25}$  and  $Al^{26}$ , both of which are in the neighborhood of 7 sec. Since there was no sweep time as large as 7 sec. available on the oscilloscope, it became evident that the general method already described would have to be modified slightly for this problem. An auxiliary sweep circuit of the desired length could have been built, but this was decided against in favor of a much simpler idea. Instead of triggering a sweep across





the face of the oscilloscope the electron beam was left focussed on a spot directly under one of the lucite tubes connected to one of the phototubes. The other two phototubes were disconnected completely. Periodically a voltage was applied to the horizontal deflection plates of the oscilloscope to move the spot out from under the lucite tube of the active phototube. This method had the definite advantage that all of the pulses from the Geiger tube were counted while the electron beam spot was focussed under the lucite tube.

The periodic application of a deflecting voltage to the horizontal deflection plates of the oscilloscope was accomplished as follows. A scaler was set to a scale of 64 and then allowed to count the 60 cycle A. C. line frequency. The resulting pulse every  $64/60$  of a second was fed into an external register. The external register had a sliding metal contact which made contact with the rotating wheel of the mechanical register. However, at definite intervals around the wheel scotch tape was placed so that the electrical contact was broken periodically. In particular the scotch tape was arranged so that the electrical contact was made for  $2(64/60)$  seconds then broken for  $3(64/60)$  seconds. For convenience hereafter  $(64/60)$  sec. will be spoken of as one time unit. With a 22 1/2 volt battery in series with the electrical contact and the horizontal deflection plates of the oscilloscope, the photo-

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tube counted for 2 time units, did not count for 3 time units, counted for 2 time units, etc.

A major difficulty arose when it was found that the pulse coming from the preamplifier following the phototube was not large enough to trigger a Tracerlab autoscanner. It had triggered an Atomic Instrument Co. Model 1030 scanner very nicely, but this scanner was not available for the purpose of counting the phototube pulses. Consequently a two-stage amplifier was designed and constructed to amplify the preamplifier pulse enough so that the autoscanner would record it. The circuit diagram of this amplifier is given in Figure 5.

Utilizing the modifications mentioned above, the following experiment was performed. A target of isotopically pure  $\text{Ig}^{24}$  was bombarded with protons of energy 324 kev. This energy is at a resonance peak for  $\text{Ig}^{24}(\text{p},\gamma)\text{Al}^{25}$ . After bombarding for thirty sec. a switch was thrown actuating the solenoid which pulled the shutter up, interrupting the Van de Graaff beam and closing the microswitch. The microswitch's closing actuated a relay which lifted a lead shield from between the target and an active Geiger tube. The Geiger tube then sent pulses to the vertical plates of the

\*Obtained from Carbide and Carbon Chemicals Division, Y-12 Area, Oak Ridge National Laboratory, upon allocation from the Atomic Energy Commission.





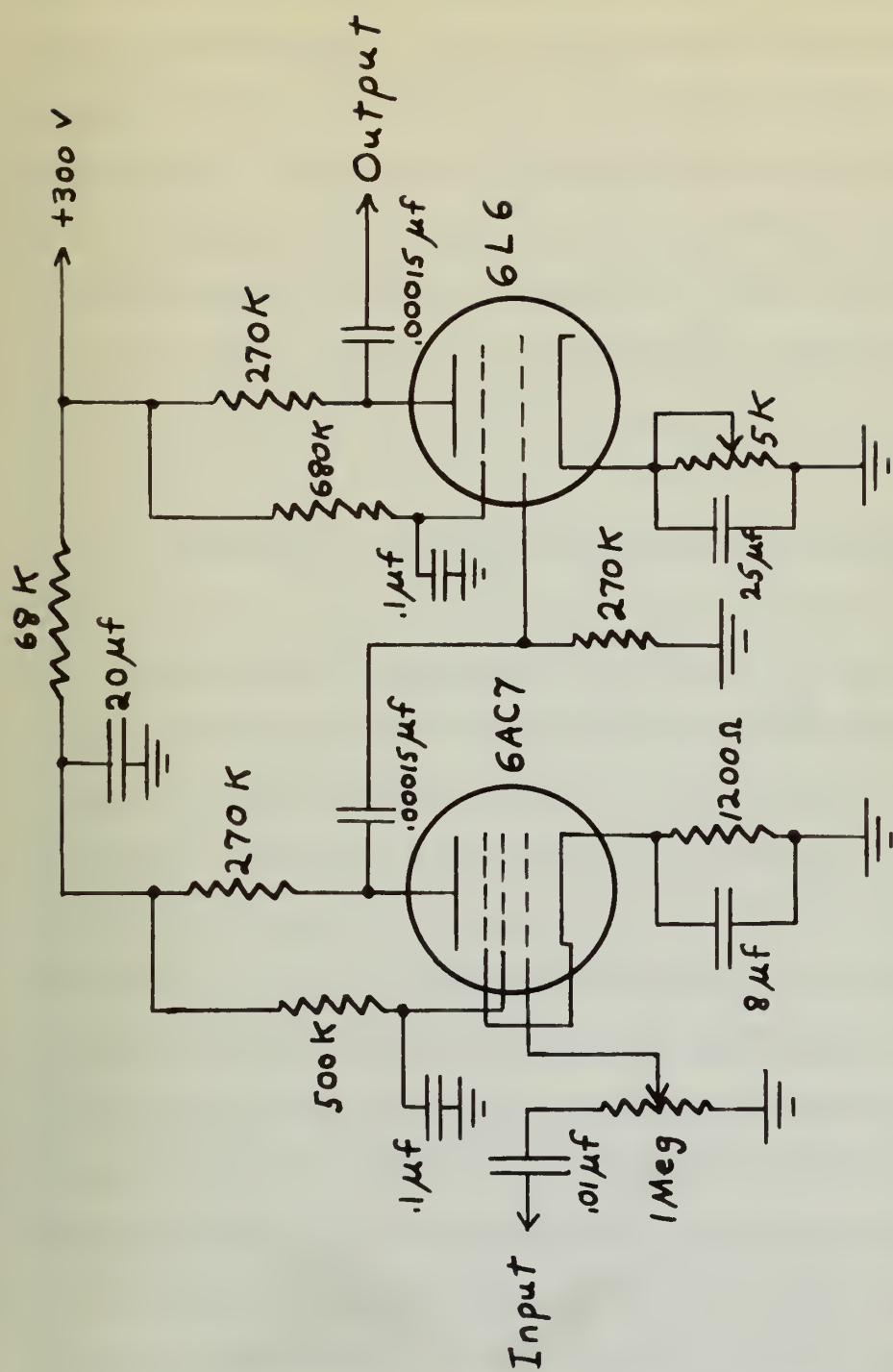
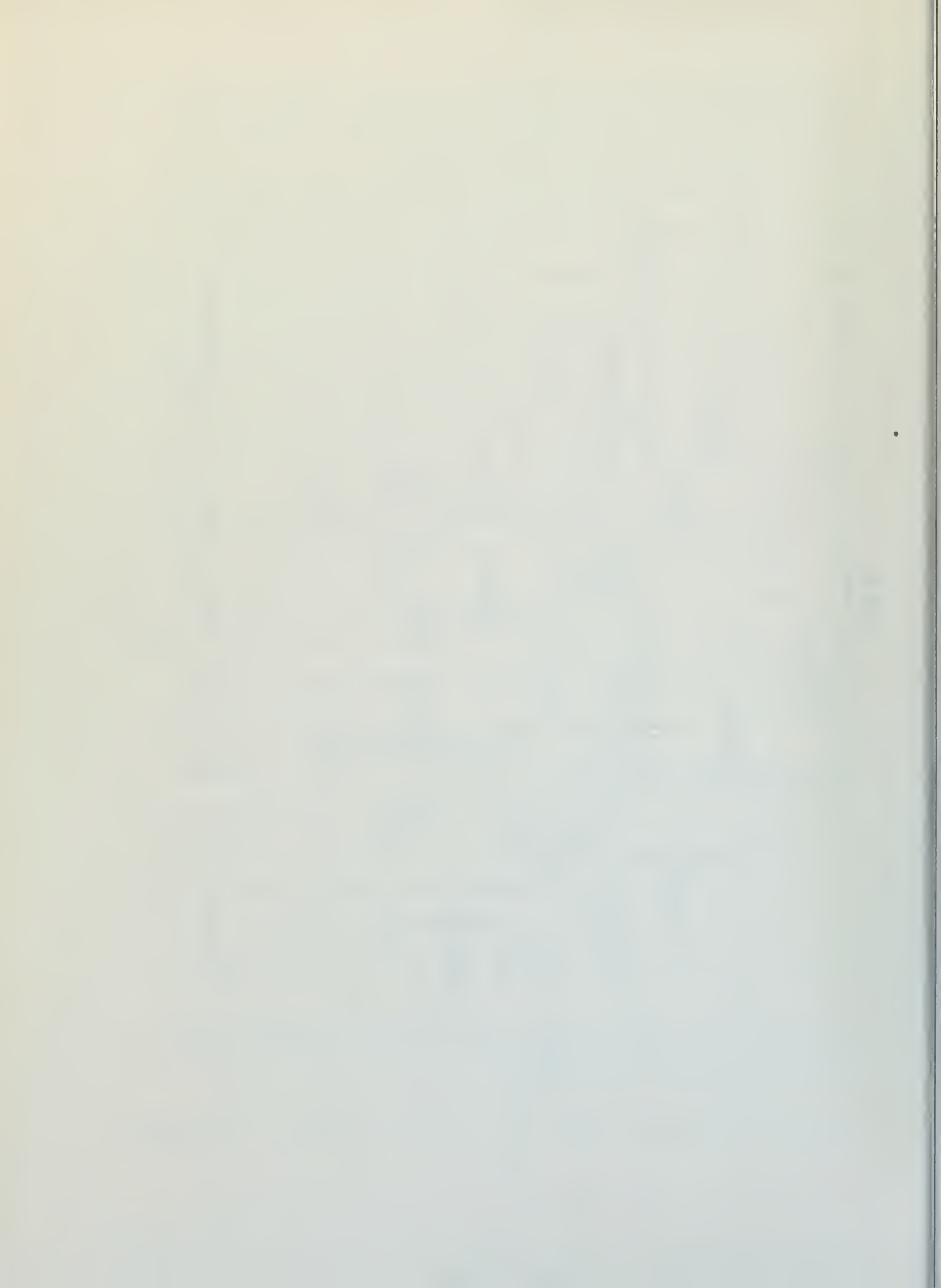


Figure 5. Circuit diagram of amplifier.



oscilloscope and the phototube counted these pulses for 2 time-unit intervals. During the three time-units delay the number of pulses registered in the preceding two time units was recorded. This sequence of events was repeated many times to get sufficient counts to insure a low probable error. The data so obtained are given in appendix I.

A similar experiment was then performed with a target of  $\text{Hg}^{25}$ , using protons of energy 565 kev. This energy is at a resonance peak for  $\text{Hg}^{25}(\text{p},\gamma)\text{Al}^{26}$ . The data obtained in this experiment are given in Appendix II.

#### Analysis of Data and Discussion of Results

In the first experiment described the nuclear reaction occurring is known<sup>(29)</sup> to be  $\text{Hg}^{24}(\text{p},\gamma)\text{Al}^{25}$  so the radioisotope whose activity would be measured is  $\text{Al}^{25}$ . All of the data obtained for the first time interval (2 time units) were added together as were those for all the other time intervals. This gave ultimately five points on the decay curve of  $\text{Al}^{25}$ . Figure 6 is a plot on semi-log graph paper of the results obtained from the data listed in appendix I. The variations plotted are one standard deviation in length. The background counting rate was measured approximately in the middle of each experiment. While taking background data the shutter was closed, with the Van de Graaff beam bombarding it, and the lead shield was raised. Before





starting to record the background counts, the induced activity of the target was allowed to decay for one minute.

The value of a standard deviation was obtained in the following manner. Suppose the total number of counts for a given time interval to be  $N$ . If there were no background counts, the standard deviation,  $\sigma$ , would be  $\sqrt{N}$ . The fact that there are background counts must be considered, however. Suppose that the number of background counts in a given time interval is  $B$ . Then the standard deviation will be

$$\sigma = \sqrt{N + B} \quad (11).$$

To actually determine the half-life of  $\text{Al}^{25}$  from the data in Appendix I a line was fitted to the data using the method of least squares. A short derivation of the theory of this method is given. (18)

Suppose a set of  $N$  points, of which only the  $y$  coordinate is susceptible to error, when plotted on graph paper suggest a linear relationship with equation

$$y = mx + k \quad (12).$$

Now, let  $d_i$  be the difference between the ordinate of the  $i$ th point and the corresponding ordinate of the line. Denote the weight of  $y_i$  by  $w_i$ . The method of least squares assumes that the best fit will be obtained when the sum of the  $w_i(d_i)^2$  is a minimum. This may be expressed as follows:

$$\sum_i w_i d_i^2 = \sum_i w_i [y_i - (mx_i + k)]^2 \quad (13)$$

is to be minimized.

The first part of the paper is devoted to the study of the  
 properties of the function  $f(x)$  defined by the equation  

$$f(x) = \sqrt{x} \quad (1)$$
 for  $x \geq 0$ . It is shown that  $f(x)$  is a continuous function  
 and that it is differentiable for  $x > 0$ . The derivative  
 of  $f(x)$  is given by the formula  

$$f'(x) = \frac{1}{2\sqrt{x}} \quad (2)$$
 for  $x > 0$ . It is also shown that  $f(x)$  is a concave  
 down function for  $x > 0$ .

In the second part of the paper, we consider the function  
 $g(x)$  defined by the equation  

$$g(x) = \sqrt{x} \quad (3)$$
 for  $x \geq 0$ . It is shown that  $g(x)$  is a continuous function  
 and that it is differentiable for  $x > 0$ . The derivative  
 of  $g(x)$  is given by the formula  

$$g'(x) = \frac{1}{2\sqrt{x}} \quad (4)$$
 for  $x > 0$ . It is also shown that  $g(x)$  is a concave  
 down function for  $x > 0$ .

The third part of the paper is devoted to the study of the  
 properties of the function  $h(x)$  defined by the equation  

$$h(x) = \sqrt{x} \quad (5)$$
 for  $x \geq 0$ . It is shown that  $h(x)$  is a continuous function  
 and that it is differentiable for  $x > 0$ . The derivative  
 of  $h(x)$  is given by the formula  

$$h'(x) = \frac{1}{2\sqrt{x}} \quad (6)$$
 for  $x > 0$ . It is also shown that  $h(x)$  is a concave  
 down function for  $x > 0$ .



Expansion of (13) leads to

$$\sum w_i d_i^2 = \sum w_i (y_i^2 + m^2 x_i^2 + k^2 - 2m y_i x_i - 2k y_i + 2k m x_i) \quad (14).$$

This may be further simplified to

$$\sum w_i d_i^2 = k^2 \sum w_i + 2mk \sum w_i x_i + m^2 \sum w_i x_i^2 - 2k \sum w_i y_i - 2m \sum w_i x_i y_i + \sum w_i y_i^2 \quad (15).$$

Consider this now as a function of the two variables  $m$  and  $k$ .

Let  $\sum w_i d_i^2 = f(m, k)$ . Now to determine the minima of  $f(m, k)$  as functions of  $m$  and  $k$  respectively one needs only to take the partial derivatives of  $f(m, k)$  first with respect to  $m$  and then with respect to  $k$  and in each case to set the result equal to zero. This gives the following two equations in the two unknowns  $m$  and  $k$ :

$$\frac{\partial f(m, k)}{\partial m} = 2k \sum w_i x_i + 2m \sum w_i x_i^2 - 2 \sum w_i x_i y_i = 0$$

$$\frac{\partial f(m, k)}{\partial k} = 2k \sum w_i + 2m \sum w_i x_i - 2 \sum w_i y_i = 0 \quad (16).$$

The solution to these equations may be written down immediately by Cramer's rule and is

$$k = \frac{\begin{vmatrix} \sum w_i x_i y_i & \sum w_i x_i^2 \\ \sum w_i y_i & \sum w_i x_i \end{vmatrix}}{D}; \quad m = \frac{\begin{vmatrix} \sum w_i x_i & \sum w_i x_i y_i \\ \sum w_i & \sum w_i y_i \end{vmatrix}}{D} \quad (17)$$

where

$$D = \begin{vmatrix} \sum w_i x_i & \sum w_i x_i^2 \\ \sum w_i & \sum w_i x_i \end{vmatrix} \quad (18).$$





This gives the solution in general.

Now in this case the actual equation of the radioactive decay being observed is

$$y = ke^{-\lambda x} \quad (19)$$

where  $x$  is the time coordinate,  $y$  is the counting rate, and  $\lambda$  is equal to  $(-\lambda)$ . To identify this situation with the straight line theory just developed one need only take the logarithm of both sides of (19) to get

$$\log_{10} y = \log_{10} k + (n \log_{10} e/x) \quad (20)$$

If one puts  $y' = \log_{10} y$ ,  $m' = n \log_{10} e$ , and  $k' = \log_{10} k$ , equation (20) becomes

$$y' = m'x + k' \quad (21)$$

which is obviously the form already treated.

It has been shown<sup>(32)</sup> that the proper weighting factor,  $w_1'$ , to use for the  $y_1'$  is  $(2.303)^2 y_1'$ . With  $y_1'$  substituted for  $y_1$  and  $w_1'$  substituted for  $w_1$ , equation (17) may be used to compute the constants  $m'$  and  $k'$  in equation (21).

The total number of counts,  $y_1$ , obtained in the  $i$ th time interval was plotted at the center of the interval. Thus it was the center of each time interval which was denoted as  $x_1$ . To be more precise one should use for  $x_1$  the quantity  $\bar{x}_1$  given by

$$\bar{x}_1 = \int_{x_0}^{x_f} xe^{-\lambda x} dx / \int_{x_0}^{x_f} e^{-\lambda x} dx \quad (22)$$

where the limits of integration are from the initial  $x$  coordinate to the final  $x$  coordinate of the  $i$ th interval,

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and  $\lambda$  is the decay constant of the radioactive material being measured. Note that an assumed value for  $\lambda$  is necessary to evaluate equation (20). Moreover the fitted value of  $\lambda$  depends on  $x_1$ ; hence a method of successive approximations must be used.

The more precise method of determining the  $x_1$ 's is not necessary if the counting intervals are of constant length, and only the slope of the decay curve is desired. The precise method should be used if one wishes to extrapolate the decay curve back to zero time.

During the actual conduction of the experiment it was observed that following the turning on of the count switch on the scaler, a brief period of time elapsed before any counts were registered. Thus the scaler seemed to have an inherent delay time between the time the count switch was turned on and counts were actually recorded. On the basis of this observation it was necessary to discard the data obtained for the first time interval since actually the scaler was not functioning properly for the full 2 time units. Thus only four points were used to determine the half-life of the radioisotopes.

Table 1 is a summary of the  $Al^{25}$  data needed to compute the half-life. The  $y_1$  were determined from the data in Appendix I, and  $\sigma$  was computed by utilizing formula (11).





$x_i$ (time units)	$y_i$ (net counts)	$\sigma_i$	$y_i^2$	$w_i^2$ ( $\times 10^9$ )	$x_i^2 w_i^2$ ( $\times 10^9$ )
6	3,192	$\pm 66$	3.30406	32.523	195.136
11	1,929	$\pm 56$	3.28533	7.176	78.956
16	1,070	$\pm 47$	3.02938	1.225	19.600
21	690	$\pm 43$	2.83825	.326	6.228
				41.254	300.524

$x_i$ (time units)	$y_i$ (net counts)	$x_i^2 w_i^2$ ( $\times 10^9$ )	$x_i y_i^2 w_i^2$ ( $\times 10^9$ )	$y_i^2 w_i^2$ ( $\times 10^9$ )
6	3,192	1,170.828	683.775	113.962
11	1,929	868.538	259.403	23.582
16	1,070	313.600	59.376	3.711
21	690	141.648	19.554	.931
		2,497.614	1,022.108	142.186

Table 1. Summary of Data for  $\text{Al}^{25}$ .

Using Table 1 and equations (17) one may easily compute  $n'$  and  $k'$ . The quantity  $n'$  is computed to be  $-.04515$  (time units) $^{-1}$ , while  $k'$  comes out to be 3.77559.

Now since  $n' = n \log_{10} e = .434n$ ,

$$n = -.04515 / .434 = -.1040 = .693 / \text{H.L.} \quad (23).$$

From equation (23) the half-life of  $\text{Al}^{25}$ , H.L., is readily found to be 6.67 time units or 7.11 sec.

It has been shown<sup>(32)</sup> that an estimate of the standard

Year	Age	Sex	Weight	Length	Wing
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110

Year	Age	Sex	Weight	Length	Wing
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110
1952, 1953	0-1, 1	Male, 1	50.2	182.5	110
1952, 1953	0-1, 1	Female, 1	50.2	182.5	110

Table 1. Summary of data for 1952.

Table 1 shows the summary of data for 1952. The data is presented in a table with 6 columns: Year, Age, Sex, Weight, Length, and Wing. The data is for the years 1952 and 1953. The ages are 0-1 and 1. The sexes are Male and Female. The weights are in grams, the lengths are in millimeters, and the wings are in millimeters. The data is presented in a table with 6 columns: Year, Age, Sex, Weight, Length, and Wing. The data is for the years 1952 and 1953. The ages are 0-1 and 1. The sexes are Male and Female. The weights are in grams, the lengths are in millimeters, and the wings are in millimeters.



error of  $m'$  may be obtained from

$$(\text{S.E. in } m')^2 = c_{22} \sigma^2(\text{ext}) \quad (24)$$

where

$$c_{22} = \sum w_i^1 / D' \quad (25)$$

in which  $D'$  is the  $D$  defined by equation (18) with  $w_i^1$  substituted for  $w_i$  and  $y_i^1$  for  $y_i$ ;

and

$$\sigma^2(\text{ext}) = \sum w_i^1 d_i^2 / (n-p) \quad (26)$$

in which  $n$  is the number of points to be fitted, and  $p$  is the number of adjustable parameters. In this case  $n-p$  is 2. Application of equation (24) leads to S.E. in  $m' = \pm .00300$  and ultimately the S.E. in the half-life of  $\text{Al}^{25} = \pm .20$  sec. Thus the half-life of  $\text{Al}^{25}$  is reported as  $7.11 \pm .13$  sec., where  $.13 = (.67)(\text{S.E.}) = \text{probable error}$ . Figure 6 is a graph of the decay of  $\text{Al}^{25}$ .

The data listed in Appendix II is summarized in Table 2. Computations precisely similar to those made for  $\text{Al}^{25}$  were performed for  $\text{Al}^{26}$ , indicating the half-life of  $\text{Al}^{26}$  to be  $7.61 \pm .21$  sec., where the  $\pm .21$  sec. is probable error. Figure 7 is a graph of the decay of  $\text{Al}^{26}$ .

The values obtained by these experiments for the half-lives of  $\text{Al}^{25}$  and  $\text{Al}^{26}$  should now be compared with values reported by other research workers using different methods. Bradner and Gow<sup>(19)</sup> have reported the half-life of  $\text{Al}^{25}$  to be 7.3 sec. They bombarded  $\text{Hg}^{25}\text{O}$  with protons from a linear accelerator and found an activity of 7.3 sec. which they





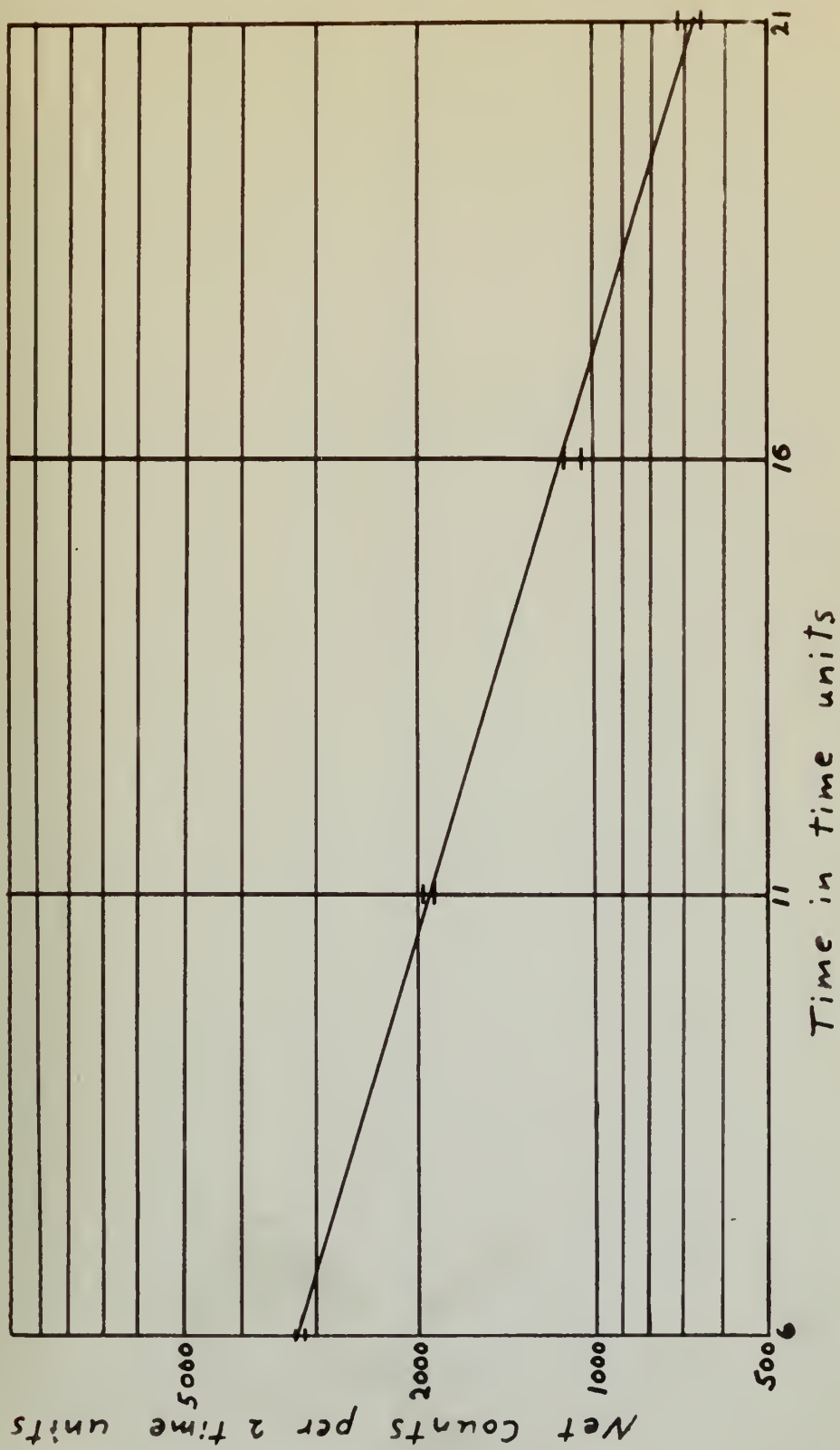


Figure 6. Decay curve of  $Al^{25}$ .



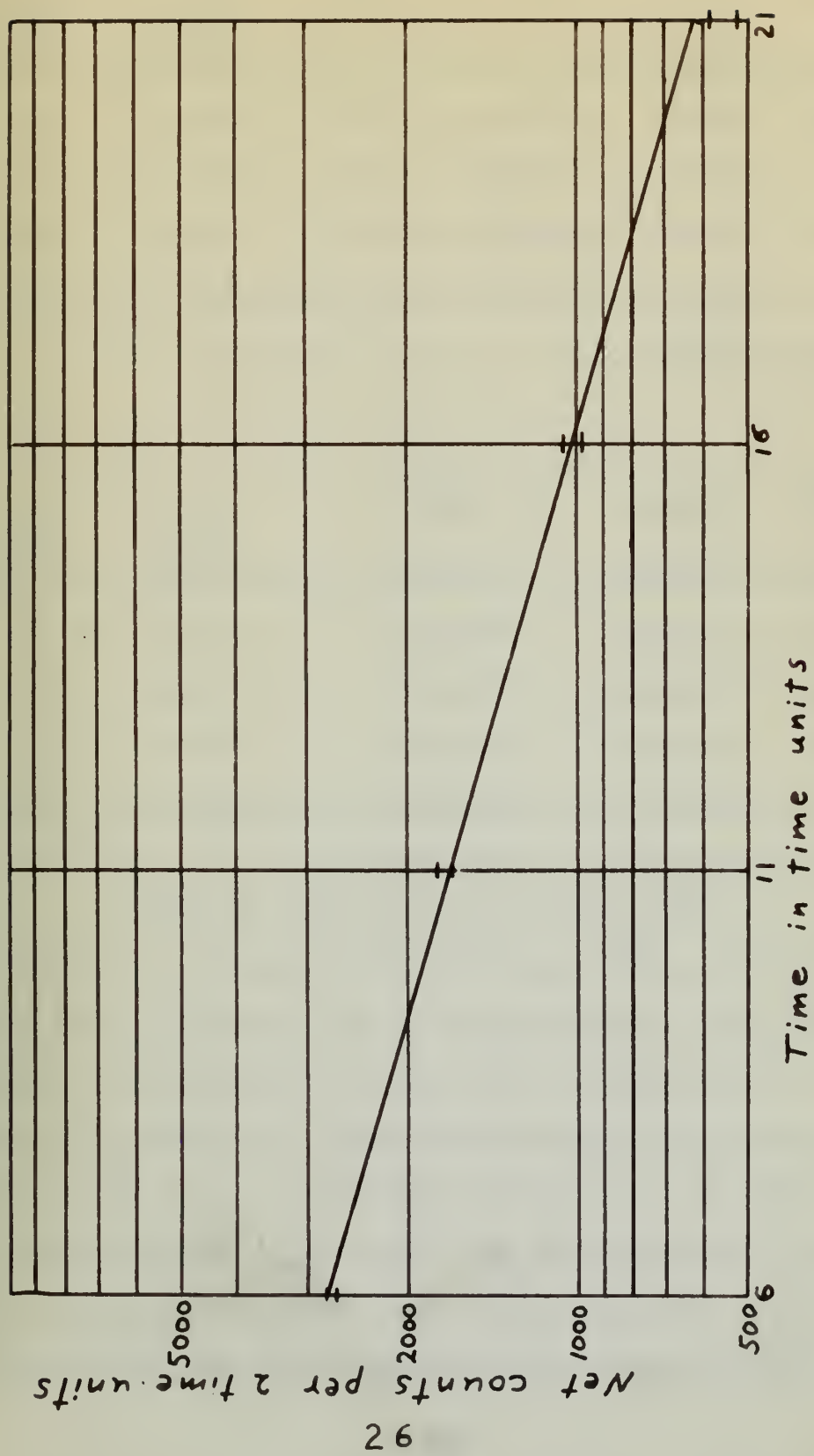


Figure 7. Decay curve of  $Al^{26}$ .





$x_1$ (time units)	$y_1$ (net counts)	$\sigma_1$	$y_1^1$	$y_1^2$ ( $\times 10^9$ )	$x_1 y_1^1$ ( $\times 10^9$ )
6	2,713	$\pm 52$	3.43365	10.959	119.214
11	1,713	$\pm 49$	3.21376	5.026	53.286
16	1,064	$\pm 41$	3.00546	1.624	15.384
21	550	$\pm 35$	2.74035	.196	1.486
				24.185	184.770

$x_1$ (time units)	$y_1$ (net counts)	$x_1^2 y_1^1$ ( $\times 10^9$ )	$x_1 y_1^1 y_1^2$ ( $\times 10^9$ )	$y_1^1 y_1^2$ ( $\times 10^9$ )
6	2,713	718.384	411.375	68.562
11	1,713	608.146	170.762	16.233
16	1,064	367.144	49.259	3.076
21	550	77.206	9.553	.432
		1,662.380	640.919	88.303

Table 2. Summary of Data for  $Al^{26}$ .

attributed to the reaction  $Fe^{25}(p,n) Al^{25}$ . It is thus seen that the results of this experiment agree quite closely with those of Bradner and Gow for  $Al^{25}$ . Bradner and Gow did not give the details of their experimental arrangement, nor the energy of the bombarding protons, nor probable error in their result. There are very few reports in the literature listing a half-life for  $Al^{25}$ . This is undoubtedly due to the fact that only recently have separated isotopes of

$\frac{1}{2}p$	$\frac{1}{2}q$	$\frac{1}{2}r$	$\frac{1}{2}s$	$\frac{1}{2}t$	$\frac{1}{2}u$
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00

$\frac{1}{2}p$	$\frac{1}{2}q$	$\frac{1}{2}r$	$\frac{1}{2}s$	$\frac{1}{2}t$	$\frac{1}{2}u$
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00
100.00	100.00	100.00	100.00	100.00	100.00

Table 1. Summary of the results of the calculations. The results are given in the form of a table. The first column gives the value of the parameter  $\alpha$ , the second column gives the value of the parameter  $\beta$ , the third column gives the value of the parameter  $\gamma$ , the fourth column gives the value of the parameter  $\delta$ , the fifth column gives the value of the parameter  $\epsilon$ , and the sixth column gives the value of the parameter  $\zeta$ . The results are given for the values of the parameters  $\alpha, \beta, \gamma, \delta, \epsilon, \zeta$  ranging from 0 to 1.00. The results are given in the form of a table. The first column gives the value of the parameter  $\alpha$ , the second column gives the value of the parameter  $\beta$ , the third column gives the value of the parameter  $\gamma$ , the fourth column gives the value of the parameter  $\delta$ , the fifth column gives the value of the parameter  $\epsilon$ , and the sixth column gives the value of the parameter  $\zeta$ . The results are given for the values of the parameters  $\alpha, \beta, \gamma, \delta, \epsilon, \zeta$  ranging from 0 to 1.00.

ing been available. The common procedure in the past has been to bombard a target of unseparated magnesium with protons. This gives a mixture of the two isotopes  $\text{Al}^{25}$  and  $\text{Al}^{26}$ , and since their half-lives are so close together, the decay curve obtained cannot in general be resolved into two components.

Quite in contrast to the case for  $\text{Al}^{25}$  there are many values reported in the literature for the half-life of  $\text{Al}^{26}$ . The latest value is 6.3 sec. and was reported by Bradner and Gow in the same article in which they reported on  $\text{Al}^{25}$ . The reaction they used in this case was  $^{26}\text{Mg}(p,n)^{26}\text{Al}$  where again the protons were supplied by a linear accelerator. Other older values<sup>(20)-(26)</sup> in the literature for the half-life of  $\text{Al}^{26}$ , however, range from 7.0 sec. to 8.5 sec., with most of the values centering around 7.0 sec. Bradner and Gow have suggested that the 7.0 sec. half-life normally given for  $\text{Al}^{26}$  is probably a mixture of  $\text{Al}^{25}$  and  $\text{Al}^{26}$ . This may be true in some cases but it is difficult to see how it could possibly be true in others. For example, Perlman and Friedlander<sup>(20)</sup> used the reaction  $\text{Al}^{27}(\gamma,n)^{26}\text{Al}$  which certainly should have given them almost pure  $\text{Al}^{26}$ . Any  $\text{Al}^{25}$  which they would have gotten would have come from the reaction  $\text{Al}^{27}(\gamma,2n)^{25}\text{Al}$  which has a very small cross section compared to the  $(\gamma,n)$  reaction. The half-life reported by them for  $\text{Al}^{26}$  was





7.0 sec. Raffler and Mirzel<sup>(21)</sup> have also used the  $\text{Al}^{27}(\gamma, n) \text{Al}^{26}$  reaction; they report the half-life of  $\text{Al}^{26}$  to be 7.2 sec. In a pioneer experiment in this field Frisch<sup>(23)</sup>, employing the reaction  $\text{Na}^{23}(\alpha, n) \text{Al}^{26}$ , obtained a value of  $7 \pm 1$  sec. for the half-life of  $\text{Al}^{26}$ . Huber et al<sup>(26)</sup>, employing the reaction  $\text{Al}^{27}(\gamma, n) \text{Al}^{26}$ , obtained a half-life of  $7.2 \pm .5$  sec. for  $\text{Al}^{26}$ . In all cases reported<sup>(22), (24), (25)</sup> where one would reasonably expect the true activity measured to be a mixture of  $\text{Al}^{25}$  and  $\text{Al}^{26}$  only a simple decay curve has been observed. This would tend to indicate that the true half-lives of  $\text{Al}^{25}$  and  $\text{Al}^{26}$  are quite close together.

The value found in this experiment for the half-life of  $\text{Al}^{26}$ ,  $7.61 \pm .21$  sec., does not agree with the 6.3 sec. of Bradner and Gow. No explanation is offered for this discrepancy other than the fact that the value found in this work does agree with that reported by researchers<sup>(26)</sup> other than Bradner and Gow. One possible explanation is that there are two isomeric states of  $\text{Al}^{26}$  with quite close half-lives.

#### Discussion of New Method's Capabilities and Limitations

It is manifestly to be regretted that there was no opportunity to conduct an experiment which would have utilized the new method in its originally described manner.

The first condition is that the function  $f(x)$  must be continuous on the interval  $[a, b]$ .  
 The second condition is that the function  $f(x)$  must be bounded on the interval  $[a, b]$ .  
 The third condition is that the function  $f(x)$  must have a finite number of discontinuities on the interval  $[a, b]$ .  
 The fourth condition is that the function  $f(x)$  must have a finite number of points where the derivative does not exist on the interval  $[a, b]$ .  
 The fifth condition is that the function  $f(x)$  must have a finite number of points where the function is not differentiable on the interval  $[a, b]$ .  
 The sixth condition is that the function  $f(x)$  must have a finite number of points where the function is not continuous on the interval  $[a, b]$ .  
 The seventh condition is that the function  $f(x)$  must have a finite number of points where the function is not bounded on the interval  $[a, b]$ .  
 The eighth condition is that the function  $f(x)$  must have a finite number of points where the function is not continuous on the interval  $[a, b]$ .  
 The ninth condition is that the function  $f(x)$  must have a finite number of points where the function is not bounded on the interval  $[a, b]$ .  
 The tenth condition is that the function  $f(x)$  must have a finite number of points where the function is not continuous on the interval  $[a, b]$ .



The main reason for deciding to measure the half-lives of  $\text{Al}^{25}$  and  $\text{Al}^{26}$  instead of any other radioisotopes was the fact that this knowledge was desired in collaboration with some work at this university of W. B. Taylor and L. H. Russell on measuring nuclear resonance peaks for the reactions  $\text{Hg}^{24} (p, \gamma) \text{Al}^{25}$  and  $\text{Hg}^{25} (p, \gamma) \text{Al}^{26}$ . The author feels certain that if time would have permitted the performance of another experiment, the apparatus described would have worked satisfactorily in its originally described way.

The main advantages of this new method are its simplicity of design, the fact that it utilizes mostly commercially available equipment, and its great flexibility of application over a wide range of half-lives, 1 millisecon. to 1 min. For all half-lives longer than 1 sec. the adaptation used in the  $\text{Al}^{25}$  and  $\text{Al}^{26}$  experiments is probably more practical than the first-described method.

One of the limitations which should be mentioned includes the large number of runs which would be necessary to insure a small probable error using the first method. Since the half-life would be computed on the basis of only three points, those points would have to be good ones. Also if the method were to be used to measure half-lives shorter than approximately  $10^{-3}$  sec., the Geiger tube should be replaced by a scintillation counter. This would be necessary



The first thing I noticed when I stepped out of the car was the cold. It was a sharp contrast to the warm blanket of the car. I shivered as I walked towards the entrance of the building. The air was crisp and clear, and I could see the stars in the night sky. The building was a large, imposing structure with many windows. Some of the windows were lit up, and I could see the silhouettes of people inside. I walked up the steps and entered the building. The interior was warm and comfortable. I was greeted by a friendly woman who showed me to my room. The room was clean and well-furnished. I took a shower and got ready for bed. I was tired from the long drive, but I was also excited to be in a new place. I went to bed and fell asleep. In the morning, I woke up and had a delicious breakfast. I then went to the office and started work. The day was busy, but I enjoyed it. I was glad to be back to work. The night was peaceful and quiet. I was happy to be in a new place and to start a new chapter in my life.

since Geiger tubes have dead times on the order of  $10^{-4}$  sec. And too many coincidence counts would be lost. Actually since scintillation counter dead times are of the order of  $10^{-8}$  sec., this method is capable of measuring half-lives on the order of  $10^{-7}$  sec. if an auxiliary fast oscilloscope sweep were constructed, and if an electronic shutter of some type were utilized.

Another minor limitation is the fact that in the modification employed in the current experiments the number of counts obtained at a given voltage setting on the 931-A phototube is very sensitive to the gain control on the amplifier used. This made it necessary to calibrate the phototube part of the apparatus by feeding a known frequency pulse from a pulse generator into the vertical deflection plates of the oscilloscope and adjusting the gain control on the amplifier until the scaler connected to the output of the phototube recorded the correct number of counts. The variable controls were not touched again then during an entire experiment. In reality this is not a serious defect since all that is actually required is that the gain remain constant over the few seconds of each individual run.

There are several radioisotopes whose half-lives might profitably be checked by this new method. Some of these are listed below, together with the reported values of the half-lives. (27), (30), (31)





Isotope	Half-life (sec.)	Reaction	Q (ev.)
$B^{12}$	2.7, $2.2 \times 10^{-2}$	$B^{11}(d,p)B^{12}$	0.4
$He^6$	.35, .37, .6	$Be^9(n,\alpha)He^6$	-0.8
$Li^8$	.43, .39	$Li^7(d,p)Li^8$	-0.30
$\Lambda^{35}$	2.2, 1.34, 1.88	$Cl^{35}(p,n)\Lambda^{35}$	-6.6
$Cl^{33}$	2.3, 2.4	$S^{32}(d,n)Cl^{33}$	.65
$S^{31}$	2.9, 3.2	$P^{31}(p,n)S^{31}$	-6.0
$Si^{27}$	4.9, 4.5	$Al^{27}(p,n)Si^{27}$	-3.4
$N^{16}$	7.3, 8	$N^{15}(d,p)N^{16}$	0.5
$Ig^{23}$	11.6, 11.9, 12	$Ka^{23}(p,n)Ig^{23}$	-4.5
$K^{12}$	$12.5 \times 10^{-3}$	$Cl^{12}(p,n)K^{12}$	-16.5
$Sc^{41}$	.67	$Ca^{40}(d,n)Sc^{41}$	.33*
$Ca^{39}$	1.06	$Ca^{40}(\gamma,n)Ca^{39}$	-14.6*
$P^{29}$	4.6	$Si^{28}(d,n)P^{29}$	-0.80
$K^{37}$	1.3	$K^{39}(\gamma,2n)K^{37}$	-24
$Ti^{43}$	.58	$Ca^{40}(\alpha,n)Ti^{43}$	-3.6*
$Cu^{58}$	3	$Ni^{58}(p,n)Cu^{58}$	-10.5*
$Er^{97}$	1-2	Fission	--
$Ab^{90-94}$	short	Fission	--
$Ca^{41}$	?	$Ca^{40}(d,p)Ca^{41}$	6.09

Of course, there are many other short-lived radioisotopes in addition to the ones listed.

\*These values were computed using mass values as given by L. Betropolis and G. Neitwiesner, "Table of Atomic Masses", Argonne National Laboratory, 1950.





Another very interesting experiment which could be done would be to measure the half-life of  $\text{Al}^{26}$  from the reaction  $\text{Mg}^{25}(\text{p}, \gamma) \text{Al}^{26}$  for different energies of the bombarding protons. Different values of half-lives at different energies would indicate the existence of isomeric states of  $\text{Al}^{26}$ . Curran and Strothers<sup>(25)</sup> performed this experiment with an unseparated Mg target in 1939, and their results suggest the possibility that indeed different half-lives might be found at different bombarding proton energies.

#### Summary

A new method of measuring short half-lives in the range from 1 millisecc. to 1 min. has been described. This method has then been applied to the problems of determining the half-lives of  $\text{Al}^{25}$  and  $\text{Al}^{26}$  with the following results:  $\text{Al}^{25}$ -7.11  $\pm$  .13 sec. ;  $\text{Al}^{26}$ -7.61  $\pm$  .21 sec. Some capabilities and limitations of the method have been discussed and future applications have been suggested.

The first of these is the fact that the  
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## References

- (1) S. Rowlands, *Nucleonics* 3, 3(1948).
- (2) J. F. Dunworth, *Nature* 144, 152(1939).
- (3) J. Rotblat, *Nature* 144, 248(1939).
- (4) J. Rotblat, *Proc. Roy. Soc. (A)* 177, 260(1941).
- (5) J. C. Jacobsen, F. Sigurgeirsson, *Bgl. Danske Videnskab. Selskab, Mat-fys. Medd.* 20, No. 11(1943).
- (6) S. Rowlands, *Nature* 160, 191(1947).
- (7) S. Rowlands, *J. Sci. Instruments* 25, 218(1948).
- (8) H.G.J. Boseloy, E. Fajans, *Phil. Mag.* 22, 629(1941).
- (9) R.A. Becker, H.A. Gaertner, *Phys. Rev.* 56, 854(1939).
- (10) J.M. Cassels, A. Lathan, *Nature* 159, 367(1947).
- (11) R.A. Sessoms, A. Sherr, *Phys. Rev.* 69, 21(1946).
- (12) D. J. Hughes, J. Dabbs, A. Cahn, D. Hall, *Phys. Rev.* 73, 111(1948).
- (13) R. L. Garwin, *Rev. Sci. Instruments* 21, No. 6(1950).
- (14) G. A. Norton, J. A. Mitchell, *Nucleonics* 4, 1(1949).
- (15) J. A. Coltman, Fitz-Hugh Marshall, *Nucleonics* 1, 5(1947).
- (16) Fitz-Hugh Marshall, J. A. Coltman, A. I. Bennett, *Rev. Sci. Instruments* 19, 744(1948).
- (17) R. Blau, B. Dreyfus, *Rev. Sci. Instruments* 16, 245(1945).
- (18) J. F. Kenny, "Mathematics of Statistics", Part One, D. Van Nostrand Co., 1939.
- (19) H. Bradner, J. D. Gow, *Phys. Rev.* 74, 1559(1948).
- (20) F.L. Farman, G. Friedlander, *Phys. Rev.* 71, 442(1948).
- (21) H. Gaffler, C. Hirszel, *Helv. Phys. Acta* 21, 200(1948).



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- (20) The twentieth is the fact that the...

- (22) H. E. Allen, E. A. Wilkinson, Proc. Roy. Soc. A 194, 131(1946).
- (23) G. E. Frisch, Nature 133, 721(1934).
- (24) E. G. White et al, Phys. Rev. 56, 512(1939).
- (25) A. C. Curran, J. E. Strothers, Proc. Roy. Soc. A 172, 72(1939).
- (26) C. Huber et al, Phys. Rev. 60, 910(1941).
- (27) Nuclear Data Circular of the National Bureau of Standards 499, Sept. 1, 1950.
- (28) G. De Benedetti, F. R. McGowan, J. E. Francis, Jr., Phys. Rev. 73, 1404(1948).
- (29) T. Tretdal, M. R. Lonsjo, R. Tangen, Phys. Rev. 77, 296(1950).
- (30) W. F. Karyak et al, Rev. Mod. Phys. 22, 291(1950).
- (31) D. D. Alburger, R. F. Hafner, Rev. Mod. Phys. 22, 373(1950).
- (32) W. S. Deming, "Statistical Adjustment of Data", John Wiley & Sons, Inc., 1943.

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# Appendix I

Data for  $^{24}\text{Mg}$  (p, $\gamma$ )  $^{25}\text{Al}$  experiment.

Background: 1024 counts in 467 sec.

All time intervals 2 time units or 2(64/60) sec. long.

The numbers recorded are 2 times the actual cumulated counts.

1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
92	162	188	226	248	46	74	96	104	112
72	86	120	132	132	40	66	102	102	116
112	194	232	302	320	12	22	24	32	32
94	122	176	210	280	152	256	304	348	358
74	110	140	174	190	126	196	230	244	270
84	148	216	228	242	146	174	196	240	260
54	84	136	158	170	12	22	22	32	44
64	108	152	152	178	30	38	42	46	64
36	60	145	144	148	62	118	134	168	184
134	214	286	296	358	46	60	140	148	150
154	172	208	260	276	108	112	166	212	220
176	292	334	356	366	78	124	150	160	160
96	150	218	274	314	38	62	94	154	166
78	136	154	174	190	72	88	144	172	208
64	98	118	118	136	134	178	218	260	264
90	102	230	266	266	120	232	282	312	350
134	248	308	450	470	124	156	194	200	212
134	172	196	222	256	58	96	142	144	188
172	304	348	354	406	60	102	132	132	140
60	204	240	260	310	54	146	164	210	230
16	22	22	38	48	30	74	122	128	128
94	116	134	164	186	82	96	110	144	128
60	110	124	140	174	116	212	274	310	320
88	124	182	206	236	76	146	160	166	172
146	204	260	290	304	118	160	174	198	212
38	86	110	13	154	76	136	164	204	206
124	204	242	254	278	86	144	168	192	216
12	66	78	122	144	112	112	140	180	180
110	214	282	332	382	114	216	288	322	374
234	324	340	324	350	126	212	304	362	376
186	328	386	424	458	136	390	436	512	532
36	76	110	110	180	78	122	148	178	198
40	76	76	80	86	92	140	192	208	236



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34	40	42	50	64
64	96	110	112	152
90	96	90	116	148
92	112	172	202	226
102	112	172	228	240
96	176	212	252	264
76	176	160	190	216
82	112	172	230	268
90	90	120	158	184
66	180	172	172	216
88	124	180	180	212
82	40	66	66	98
58	66	130	140	156
72	126	146	152	160
108	158	196	210	216
126	172	236	270	294
108	248	262	282	290
108	148	162	174	212
36	74	84	94	94
16	38	54	60	60
58	170	126	172	172
88	150	158	184	216
12	56	82	106	124
90	126	172	202	220
54	72	72	72	76
75	112	150	182	196
82	86	126	144	148
100	166	224	236	260
92	104	158	200	256
94	142	162	182	200

72	118	194	234	238
88	156	162	180	212
68	180	222	242	252
104	162	200	210	236
82	186	248	258	284
102	168	238	246	314
90	178	272	304	310
74	202	222	260	278
106	174	224	250	266
44	128	172	172	194
92	200	250	280	292
120	186	220	242	246
82	136	160	186	198
168	236	314	368	412
86	148	210	236	236
132	170	208	268	276
96	204	250	314	376
46	118	148	186	186
126	160	258	308	384
114	228	246	292	292
72	184	206	224	256
120	238	298	340	372
76	186	212	244	272
132	192	264	288	302
140	244	282	348	368
86	236	278	300	336
152	196	224	236	242
156	238	336	348	386
138	216	262	320	348
192	276	358	362	416

	1st	2nd	3rd	4th	5th
Sum	11,308	18,872	23,910	27,230	29,790
÷ 2	5,654	9,436	11,955	13,615	14,895
Differences	5,654	3,782	2,519	1,660	1,280
- D. G.	5,664	3,192	1,929	1,070	690

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# Appendix II

Data for  $\text{Fe}^{55}$  ( $\text{p}, \gamma$ )  $\text{Al}^{26}$  experiment.

Background: 73% counts in 1,333 sec.

All time intervals 2 times as  $2(54/10)$  sec. long.

The numbers recorded are 2 times the actual cumulated counts.

1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
24	34	44	50	56	12	22	26	30	34
36	24	44	52	56	6	30	24	12	36
4	12	30	40	50	12	56	66	72	74
24	30	70	40	42	20	44	50	62	66
16	34	22	70	74	20	56	72	82	80
26	42	52	56	64	24	38	48	54	64
34	60	84	96	108	56	72	825	94	100
18	42	60	68	72	26	36	52	60	68
34	48	54	58	60	30	56	72	82	96
34	60	72	84	88	56	70	90	102	106
12	26	36	38	42	24	34	44	56	64
40	74	84	100	110	14	40	52	56	64
48	64	72	92	92	22	48	72	82	92
32	58	78	92	96	36	56	66	68	72
38	56	70	76	80	24	36	50	64	70
30	52	76	80	80	34	78	106	122	128
40	76	106	122	134	44	76	94	107	106
28	66	78	78	90	28	48	58	66	74
26	38	52	66	70	12	28	32	46	56
26	54	68	90	102	44	64	76	84	96
40	68	78	88	94	36	58	68	80	90
46	74	96	96	100	24	36	50	54	66
40	64	90	60	66	12	16	24	34	36
14	22	44	28	30	4	4	36	40	42
6	8	14	14	12	10	16	24	24	26
10	12	18	20	24	20	28	34	36	64
24	50	70	82	88	40	76	100	126	134
44	68	88	96	102	32	50	70	72	74
34	58	70	80	82	32	60	64	96	96
32	78	84	112	112	46	74	90	100	104
52	74	106	114	124	38	42	52	56	70
30	60	72	92	88	36	60	106	124	138
32	60	62	88	88	44	82	120	132	126
50	50	70	86	90	50	68	76	64	86
62	80	108	112	112	16	44	50	66	78















32	44	62	68	76
34	46	64	70	78
36	48	66	72	80
38	50	68	74	82
40	52	70	76	84
42	54	72	78	86
44	56	74	80	88
46	58	76	82	90
48	60	78	84	92
50	62	80	86	94
52	64	82	88	96
54	66	84	90	98
56	68	86	92	100

32	44	62	70	82
34	46	64	72	84
36	48	66	74	86
38	50	68	76	88
40	52	70	78	90
42	54	72	80	92
44	56	74	82	94
46	58	76	84	96
48	60	78	86	98
50	62	80	88	100
52	64	82	90	102
54	66	84	92	104
56	68	86	94	106

Sum	1st	2nd	3rd	4th	5th
÷ 2	9,134	15,260	19,386	21,152	23,702
Differences	4,567	7,630	9,692	11,031	11,251
- 1. 2.	4,567	3,063	2,063	1,550	800
	4,217	2,713	1,713	1,065	599

1. The first part of the paper discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business and for the protection of the interests of all parties involved.

2. The second part of the paper describes the various methods used to collect and analyze data. It includes a detailed discussion of the different types of data that can be collected and the various techniques used to analyze this data.

3. The third part of the paper discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business and for the protection of the interests of all parties involved.

4. The fourth part of the paper describes the various methods used to collect and analyze data. It includes a detailed discussion of the different types of data that can be collected and the various techniques used to analyze this data.

5. The fifth part of the paper discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business and for the protection of the interests of all parties involved.

6. The sixth part of the paper describes the various methods used to collect and analyze data. It includes a detailed discussion of the different types of data that can be collected and the various techniques used to analyze this data.

7. The seventh part of the paper discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business and for the protection of the interests of all parties involved.

8. The eighth part of the paper describes the various methods used to collect and analyze data. It includes a detailed discussion of the different types of data that can be collected and the various techniques used to analyze this data.

9. The ninth part of the paper discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the success of any business and for the protection of the interests of all parties involved.

10. The tenth part of the paper describes the various methods used to collect and analyze data. It includes a detailed discussion of the different types of data that can be collected and the various techniques used to analyze this data.

The following table shows the results of the experiments conducted over a period of six months. The data was collected from a large number of subjects and analyzed using the methods described in the paper.

The results show that the use of the proposed method significantly improved the accuracy of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

The results also show that the use of the proposed method significantly improved the efficiency of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

The results also show that the use of the proposed method significantly improved the reliability of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

The results also show that the use of the proposed method significantly improved the validity of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

The results also show that the use of the proposed method significantly improved the consistency of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

The results also show that the use of the proposed method significantly improved the completeness of the data collection process. This was achieved by using a combination of different techniques to collect and analyze the data.

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